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DEVELOPMENT OF A TECHNIQUE OF STRENGTH AND RIGIDITY CALCULATIONS OF MECHANISMS AND MANIPULATORS TAKING INTO ACCOUNT THE DISTRIBUTED DYNAMIC LOAD

ABSTRACT

of the dissertation in partial fulfillment of the requirements
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Relevance of the research. One of the important problems in the design of mechanisms and manipulators is to ensure the strength and stiffness of their links in the full working process.

For the analysis of the stress-strain state of rod systems, basically, there are three approaches. The first of them is graph-analytical method for statically indefinable and fixed rod systems, which include the method of forces and the method of displacements. The second approach to solving the problem of dynamic calculation of elastic systems is the method of lumped parameters, which is based on the idea of an approximate replacement of a system with an infinite degree of freedom with a system with a finite degree, by replacing the distributed mass with a concentrated one. The third of the most common modern numerical methods allowing solving problems of a static, dynamic stress-strain state of structures is the finite element method. However, in these graph-analytical and numerical methods for calculating mechanisms and manipulators for strength and stiffness, the distributed dynamic loads are not taken into account.

In order to more accurately predict the nature of the stress-deformable state of moving linkages, it is necessary to take into account, in addition to static concentrated loads applied to the system, also distributed dynamic loads depending on the physical, geometric and kinematic characteristics of the links. Therefore, the development of an analytical method to determine the internal forces and displacements in the links of moving linkages is urgent. The advantage of the analytical method is obvious – the accuracy and speed of calculation. Since all rod systems have a distributed mass, they are always systems with a degree of freedom equal to infinity. Consequently, it is necessary to develop such a discrete model of the mechanism so that the internal forces of each link are uniquely determined by a finite set of internal forces in its individual sections, and then the task will be reduced to calculating the internal forces in the final number of cross-sections of links.

In addition, the development of an algorithm for minimizing the total mass of designed mechanisms and manipulators with restrictions on allowable stresses in the links, the results of which allow to choose a rational form of cross-sections and determine the transverse dimensions of cross-sections of links with the smallest area, ensuring the strength of links in the full working process under the action of static and distributed dynamic loads on the links of designed linkages at various speeds and accelerations of generalized coordinates.

The aim of the dissertation is to develop a technique of strength and rigidity calculations of mechanisms and manipulators taking into account the distributed dynamic load.

The object of the research are planar mechanisms and manipulators.

The subject of the research are the strength and stiffness of planar mechanisms and manipulators.

According to the aim, **the research objectives** are as follows:

- development of the kinematic characteristics of planar mechanisms and manipulators required to determine the longitudinal and transverse distributed dynamic loads in the links;
- development of computer programs, allowing the animation of the movement of the mechanisms and manipulators with the construction on the links of diagrams of longitudinal and transverse distributed dynamic loads;
- development of algorithms for analytical determination of internal forces in the links of mechanisms and manipulators under the influence of static and distributed dynamic loads;
- creation of computer programs, allowing animation of the movement of the mechanism and manipulators with the construction on the links of diagrams of bending moments, transverse and longitudinal forces;
- development of algorithms for analytical determination of longitudinal, transverse displacements and rotation angles of cross-sections;
- creation of computer programs, allowing to make animation of movement of the mechanism with the construction on the links of diagrams of longitudinal, transverse displacements and angles of rotation of the cross-sections of the links;
- development of algorithms and creation of computer programs that minimize the total mass of mechanisms under stress constraints in the links;
- to obtain numerical results, where the cross-section shapes will be selected and their linear dimensions will be determined to ensure the strength of the links in the complete workflow.

Methods of the research: modern analytical and numerical methods for solving problems of machine mechanics.

The scientific novelty of the work is as follows:

- a technique for strength and rigidity calculations of planar mechanisms and manipulators taking into account external concentrated and distributed dynamic loads has been developed;
- the algorithms were developed and the computer programs were created that allow the animation of the movement of mechanisms and manipulators with the construction of distributed dynamic loads and internal forces on the links;
- the algorithms were developed and the computer programs were created that allow the animation of the movement of the mechanisms with the construction of the diagrams of the deformations on the links;
- the algorithms were developed and the computer programs were created that minimize the total mass of mechanisms with restrictions on the allowable stresses in the links and the numerical results were realized, i.e. shapes of cross-sections of links were selected and their linear dimensions were determined, ensuring the strength of the links during the full working process on the example of a planar six-bar mechanism.

Theoretical and practical significance of the research. The developed methodology can be used to conduct further theoretical studies of the stress – deformable state of the elements of spatial moving systems (spatial linkages, manipulators, trusses, frames, etc.) with static definable and indefinable structures. The practical significance of the research consists in the application of the developed methodology in the study of the stress-strain state of the designed and existing linkages (planar mechanisms, manipulators, trusses, frames, etc.).

The reliability and validity of scientific statements, conclusions and results of the dissertation. The basic calculation equations used in the dissertation are obtained using the correct principles of theoretical mechanics, mathematical analysis, higher algebra, differential equations, fundamentals of robotics, the theory of machines and mechanisms, and the mechanics of a deformable solid body.

In developing the algorithms and creating computer programs, the calculated equations obtained in the thesis work and the capabilities of the Maple software were used. The reliability of the results is clearly visible in the animation of the movement of the mechanism under consideration with the construction of diagrams of internal forces and deformations according to the following features: (a) between the intensity of transverse dynamic loads, transverse forces, bending moments and the intensity of the longitudinal dynamic loads, angles of rotation of cross-sections and deflections, longitudinal forces and longitudinal movements of cross-sections of links there are differential dependences that can be used for checking the results; (b) boundary conditions in racks, articulated nodes, etc.

The obtained linear dimensions of cross-sections of links can be checked by determining the stress in any section of any link and in any position of the mechanism; this value should not exceed the allowable stress.

The connection of the dissertation with other research. This work was performed in the framework of the projects of the grant funding of fundamental research in the natural science field of the Ministry of Education and Science of the Republic of Kazakhstan “Development of analytical theory of prediction strength and stiffness of robotic systems and mechanisms” (years 2015-2017, № ГР 0115РК00783).

Approbation of the work. The main provisions and results of the dissertation were reported and discussed at the following scientific events:

- International Scientific-Practical Conference: «One hundred concrete steps. Modern state for all» - a strategic path for the industrial and innovative development of the country (Shymkent, Kazakhstan, October 29-30, 2015);
- 7th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2016) (Crete, Greece, June 5-10, 2016);
- Republican Scientific-Methodical Conference "Actual problems of mechanics and mathematics", dedicated to the 20th anniversary of L.N. Gumilyov Eurasian National University and the 10th anniversary of the founding of the department "Mechanics" of the Mechanics and Mathematics Faculty of L.N. Gumilyov Eurasian National University (Astana, Kazakhstan, November 14-15 ноября, 2016);
- 2nd International Conference on Robotics, Control and Automation (ICRCA 2017) (Kitakyushu, Japan, September 15-18, 2017);
- scientific seminars of the Department of Mechanics of al-Farabi KazNU (Almaty, Kazakhstan, 2015-2018).

Publications. The author published 8 works on the topic of the dissertation, including 3 publications in scientific journals recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan for publishing the main results of scientific activity; 1 publication in scientific journal and 2 publications in the proceedings of international conferences indexed by Scopus and Web of Science; 2 publications in the proceedings of domestic scientific conferences.

Personal contribution of the author:

- participation at all stages of the development of a technique for strength and rigidity calculations of planar mechanisms and manipulators taking into account external concentrated and distributed dynamic loads;
- the direct participation of the applicant in the development of programs, allowing the animation of the movement of the mechanism and manipulator with the construction on the links of the diagrams: of longitudinal and transverse distributed dynamic loads; of bending moments, transverse and longitudinal forces; of transverse and longitudinal displacements and rotation angles of cross-sections of links and determining the linear dimensions of cross-sections with the smallest area,

ensuring the strength of links in the full working process of the mechanism;
- personal participation in testing the results of the research;
- preparation of the main publications on the work performed.

Structure and scope of the dissertation. The dissertation includes the title page, the content, an introduction, five chapters, a conclusion and a list of references consisting of 65 titles. The total volume of the dissertation is 91 pages, including 45 illustrations and 2 tables.

The main content of the dissertation. The introduction includes the substantiation of the relevance of the dissertation research topic, the purpose of the work, the object, the subject, the research objectives, the description of the applied methods, scientific novelty, theoretical and practical significance, the main provisions to be defended, information on published works on the topic of the dissertation and the degree of its development.

The first chapter of the thesis is devoted to the kinematic analysis and determination of the laws of distribution of transverse and longitudinal dynamic distributed loads along the links. The computer programs have been developed, which allow the animation of the movement of the mechanism and manipulator with the construction of the diagrams of the longitudinal and transverse distributed dynamic loads.

In the second chapter of the dissertation, the matrices of approximations of links and internal forces expressed with the help of the matrix of approximations and the required vectors of forces in the calculated cross-sections are given, as well as the computational and conditional schemes for the construction of discrete models of elements and mechanisms. For the elastic calculation of rod mechanisms, on the basis of the D'Alembert principle, the mechanisms were brought to the structures (calculation schemes of the mechanism), the degree of movement of the value is zero. To determine the internal forces in the links (elements) of the design scheme of the mechanism, the construction is divided into elements and nodes. To construct a discrete model of the elements, conditional schemes were applied, which show what the required values of internal forces are measured in the considered cross-section. Discrete models of elements with constant cross-sections and a discrete model of the whole mechanism are constructed.

The third chapter presents the dynamic equilibrium equations of the discrete element, as well as the dynamic equilibrium equations of the nodes under the action of concentrated and distributed dynamic loads. In the dynamic equilibrium equations of the discrete element and the nodes the connection between the vector of forces in the calculated cross-sections and the geometric, physical and kinematic characteristics of the element was established. By combining the dynamic equilibrium equations of the discrete element and the nodes in the one system, we obtain the resolving equilibrium equations for the entire discrete model of the

mechanisms and manipulators. The algorithms for the analytical determination of internal forces in the links of mechanisms and manipulators with statically definable structure are developed, in cases where the links of mechanisms and manipulators are under the action of concentrated forces, as well as transverse and longitudinal distributed dynamic loads. According to the developed algorithm, computer programs were created, allowing animation of the movement of the mechanism and manipulator with the construction on the links of the diagrams of bending moments, transverse and longitudinal forces.

In the fourth section, we used the differential equation of the elastic line of the beam to determine the transverse displacements and the angle of rotation of the cross-sections of the links, and to determine the longitudinal displacements of the points of the links was used the Hooke's law. The algorithms were developed for determining the constants of integration in the equations of transverse and longitudinal displacements in links. Links are considered as elements with fixations, given in the design scheme of the mechanism. The determination of the integration constant in these equations allows one to determine the angles of rotation, transversal and longitudinal displacements of the cross-sections of the links. Based on the developed algorithm, computer programs have been created that allow to animate the movement of the mechanism with the construction of angles of rotation in the links, transversal and longitudinal movements of the cross-sections of links under the action of dynamic distributed and external concentrated loads.

In the fifth chapter, an algorithm is developed for minimizing the total mass of designed mechanisms and manipulators with restrictions on the allowable stresses in the links. The results of these research allow choosing the shape of the cross-sections and determining the linear dimensions of cross-sections of links with the smallest area, ensuring the strength of the links in the full working process of the designed planar mechanisms and manipulators under static and dynamic loads. Numerical results – the geometric characteristics, the linear dimensions of the cross-sections, the maximum values of the internal forces and the weights of the links of the six-bar mechanism under consideration were determined.

In conclusion, the main results and conclusions of the dissertation research, assessment of the completeness of the solution of the tasks, recommendations and baseline data on the specific use of the results, assessment of the technical and economic effectiveness of implementation, assessment of the scientific level of the work performed in comparison with the best achievements in this field are presented.